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Changes of soil environment and their effect on crop productivity in desertification processes of sandy cropland

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Introduction

Soil is a primary base for all terrestrial plants living on it. Soil environment, such as soil nutrient, soil moisture and soil temperature, plays an important role in the composition and abundant of plant species, and have in the productivity of land (Cheng Weixin. 1985. Liang Zhenxing, 1994.). For higher and stable output, there must be a health soil environment for crop growth. There have been many literatures of deep insights on the relationship between crop yields and soil moisture and nutrients, supplying scientific principles for improving soil environment and making a progress in agriculture (Xie Xianqun, 1992. Zhao Aifen, 1999. Wang Deshui. 1995.)

Rainfed Cropland is a larger portion of the total cropland in Horqin Sandy Land. And its productivity is very low, large area of the cropland has been degraded into desertified land due to dry and very windy spring, loose soil texture vulnerable to wind erosion and mismanagement (Cheng Weixin. 1985. Zhu Zhenda, 1994. Liu Xinmin, 1993.). Scientists have paid much attention on the causes, processes and damages of desertification (Zhu Zhenda, 1994. Liu Xinmin,1993. Li Yulin, 2000. Zhu Zhenda, 1980. Zhao Halin, 1998. Zhao Halin, 1999.) However, few papers on soil environmental evolvement and its influence on land productivity have been reported in this area.

Horqin Sandy Land located in the semi-arid area of agro-pasturage in eastern part of Inner Mongolia Autonomy Region. In comparison with Maowusu Sandy Land and Hunshandake Sandy Land, Horqin has a better water and thermal condition. Therefore, it has been a base for food and animal production in Inner Mongolia Autonomy Region since 1949 (Wang Deshui. 1995. Liu Xinmin, 1996.). Now, Horqin is one of the most severe desertified areas in northern part of China because of over-cultivation of grassland into cropland, over-grazing and over-collection of fuel-wood by local farmer. The aim of this paper is to present the changes of soil environment with the development of desertification, assess the effect of desertification on land productivity, and provide some suggestions on soil improvement of desertified croplands.

Materials and Methods

Study Site

The experiment site situated in Naimanqi (120°19'—121°35' E, 42°14'—43°32' N£¬a.s.l. 340-360 m), which locate in Horqin Sandy Land, Inner Mongolia, China. It is a semi-arid and continental climate. The annual mean temperature is 6.4°C. The annual accumulated air temperature that is more than and equal to 10°C is 3151.2°C. The frostless period is 130-167 days. The annual mean precipitation is 365 mm, and the annual mean evaporation is 1972 mm. The annual mean wind speed is 3.4 m/s, and the frequency of wind with more than 5 m/s, which is recongnised as threshold of wind velocity leading to wind erosion, is 524 times per year. The typical soils are sandy meadow soil and aeolian sandy soil. The characteristics of those soils are higher sand particle contents, low soil nutrient, and bad plasticity, fragile to erode by wind erosion. The study site is on aeolian sandy soil, whose thickness is from 30 to 40 cm depth, and under which is

alluvial coarse sandy soil.

Methods

A transect along the gradient of desertification was set up in a large cropland with gentle topography and wind eroded. According to the degree of desertification, four type of cropland can be distinguished, non-desertification (ND), slight-desertification (LD), moderate-desertification (MD) and severe- desertification (SD), each including four replication and two permanent quadrates, one for determining soil moisture, the other for investigating of crop growth. The cultivar green bean was sown on 20th Apr. and harvested on 10th Sep. Nitrogen was applied as urea (46% N) at 75 kg/ha. Items measured were height, basal diameter, LAI, above-ground biomass by harvesting at adjacent plot, soil temperatures (at 0, 5, 10, 15, 20, 30cm depth, respectively) by Digital Thermometer (Chino-ND500, Japan), the heat value of biomass by oxygen bomb calorimeter (PARR-3430) and soil moisture (at 0-5, 6-10, 11-20, 21-30, 31-40, 51-60cm depth, respectively) by gravimetric method at intervals of every 10 days after 14th May.

Statistical analyses of correlation and regression were carried out with the SPSS programme (SPSS 10, 1998).

Results

Changes of soil particle size due to desertification

The composition of soil particle size at four treatments shows in Table 1. Along with development of desertification, compared with ND, the sand content in SD is increased by 140%, but the clay content in SD is decreased by 82.3%. The hygroscopic water content was decreased by 82.1% because of high sand content in SD. The more severe desertification, the higher sand content of the cropland soil is for wind blowing the clay away. (Zhao Halin, 1986. Zhou Ruilian, 1995.).

Table1 Changes of farmland soil particle size (%) in desertification process

Treatments	0.05-1.0 mm	0005-0.05 mm	<0.005 mm	Hygroscopic moisture	wish off
ND	32.2	33.0	30.6	2.35	3.2
LD	52.0	38.9	7.9	0.74	1.2
MD	52.8	42.0	5.1	0.49	0.7
SD	77.3	26.5	4.8	0.42	0.4

Changes of soil nutrient

Along with the development of desertification, the soil nutrient content of cropland decreased dramatically as shown in table 2. Comparing to ND, the OM, total N, total P, total K, available N, available P, and available K decreased by 66.2%, 72.8%, 59.4%, 9.3%, 69.0%, 27.5%, and 56.3% in SD, respectively.

Soil nutrient environment is a basic element for crop growth and reproduction. Soil nutrient content directly affect crop yield. Therefore, desertification for deteriorating the soil environment popularly recognized as the leading factor resulted in low and unstable crop yield in this region.

It also was found that soil OM, total N, available N, available K were decreased consistently, however the total P and available P presented a fluctuating trend as shown in table 2.

Table2 Changes of soil nutrient in desertification process

Items	Organic matte (%)	Total N £¨%£©	Total P £¨%£©	Total K£¨%£©	Available N£¨mg/kg£©	Available P£¨mg/kg£©	Available k£¨mg/kg£©
ND	1.48	0.103	0.032	2.70	42.0	4.0	167.0
LD	0.61	0.039	0.017	2.75	28.0	5.0	85.0
MD	0.59	0.039	0.025	2.56	18.0	3.0	85.0
SD	0.51	0.028	0.013	2.45	13.0	2.9	73.0

Changes of soil moisture

Changes of soil moisture in all treatments were shown in Fig. 1. The mean value of soil moisture in whole growth period in ND is significantly higher than that in LD, MD, and SD. Along with desertification, the soil moisture of cropland was diminished. As compared to ND, the soil moisture in LD, MD, SD, had was reduced to 46.4%¡¢54.3% and 74.8%, respectively. The soil moisture in ND was 12.4% at drought period, 21.4% at monsoon period, and still around 9.2% during the most drought phase. It was correspondingly 2.4% 5.8%, and 2.3% in SD. Apparently, the water demand of green bean for growth can be met in ND. Nevertheless, it was difficult for crop to growth under such lower soil moisture in SD.

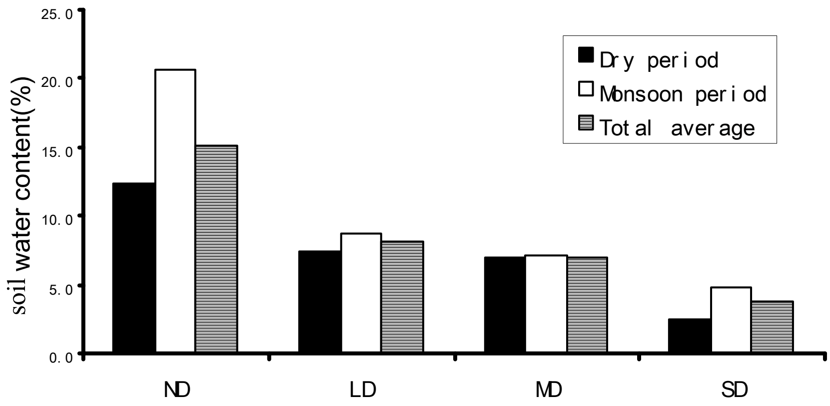


Fig.1 Season changes of soil water content¡¡

Changes of soil temperature

With coarse particle increase in soil, soil thermal efficiency and thermal exchanges became poorer in desertification cropland (Li Yulin, 2000). Meanwhile, the fluctuation of soil temperature at topsoil layers was larger than that at deep ones, and the soil temperature at tillage layer increased in SD. The average soil temperature at 5- 30 cm depth was low in ND, and high in SD (Fig. 2). Soil temperature at ND, LD, MD and SD was 21.5°C, 22.0°C, 22.1°C and 22.4°C, respectively. Difference of soil temperatures between the maximum and minimum was 0.9°C. Cropland with high soil temperature in summer, had a disadvantage for biomass accumulation and soil moisture maintenance (Li Yulin, 2000.).

Formation of crop biomass

The processes of crop biomass forming at ND, LD, MD, and SD were shown in Fig. 3. In ND the rapid growth period of green bean was from 4 July to 25 Aug., but in SD from15 July to 4 Aug. The daily rate of biomass accumulation in ND increased continuously and steadily. However, in desertified area, the rate increased irregularly. The more serious desertification occurred in cropland, the larger fluctuation of the daily rate of biomass accumulation can be found in Table. 3. All those indicated that desertification had brought out

the changes of soil environment and influenced significantly on the rhythm of crop growth. The developing of desertification would result in remarkable decreasing of crop biomass. The biomass in LD, MD and SD had decreased by 15.3%¡¢31.1%, 60.5%, compared to ND, respectively.

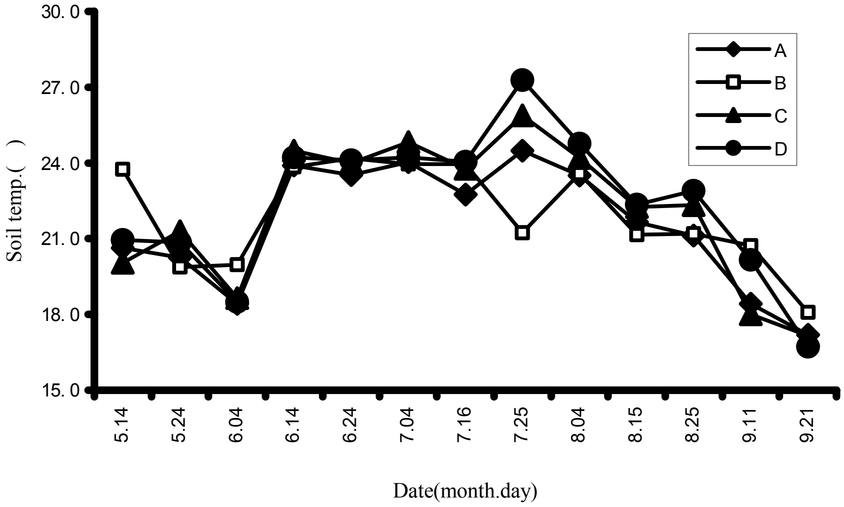


Fig.2 Seasonal changes of soil temperature in 5-30cm depth
a. non-desertification; b. slight-desertification; c. moderate-desertification; d. severe-desertification

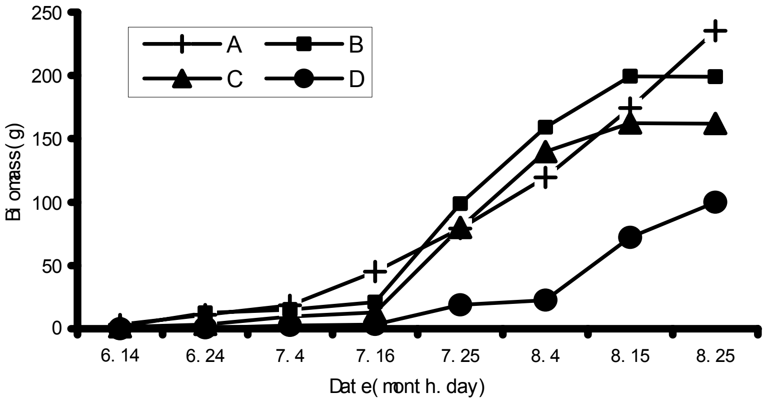


Fig.3 Formation processes of biomass in farmlands

Table3 Accumulating rates of biomass in farmlands (g/days)

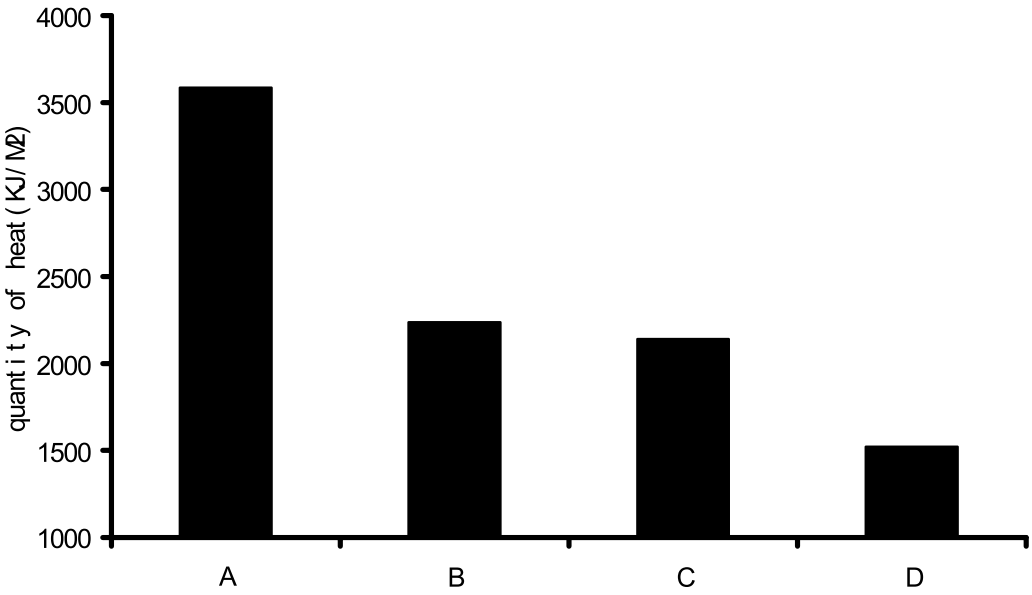
Items	6.14-6.24	6.25-7.04	7.057.16	7.17-7.25	7.26-8.04	8.05-8.15	8.16-8.25
ND	0.8	0.8	2.2	3.8	4.0	5.0	6.1
LD	1.1	0.2	0.5	8.7	6.0	3.6	0.0
MD	0.2	0.7	0.3	7.4	6.0	2.0	0.0
SD	0.1	0.2	0.0	1.8	0.4	4.5	2.8

Comparison of photosynthetic efficiency in different treatments

The heat values of biomasses from different treatments in unit area were shown in Fig. 4. The heat value in ND is 3.585 MJ/m^2, larger than that in LD. The biomass of green bean in ND was 2.36 times that in SD. The photosynthetic efficiency were 0.37%¡¢0.23%¡¢0.22% and 0.16% in ND,

LD, MD and SD, respectively. These indicated that the photosynthetic efficiency and the energy that input to cropland-system decreased with cropland desertification. Thus, desertification was harmful to agricultural production and cropland –system development.

Fig.4 Comparison of heat value among farmlands



Relationship between factors of soil environment and cropland productivity

As above, in the processes of desertification the cropland productivity decreased remarkably because of the continuous deterioration of soil environment. The results of correlation analysis showed the crop yield had a close relationship to available N, soil moisture and total K, and their relative coefficient were 0.9423¡¢0.9202 and 0.9096, respectively. However, the soil temperature had a negative effect on crop yield, and the relative coefficient was 0.9475 (Table 4). Analysis also revealed that soil OM had a significant relationship with the amount of soil particle size at 0.005mm. The soil OM and the amount of soil particle size at 0.005mm had a considerable effect on soil moisture. The soil temperature was increased due to a high content of coarse sand and low soil moisture at desertified cropland. Soil moisture, soil OM content and total nitrogen took a great effect on the content of soil available nitrogen. Those results showed that crop yield was decreased remarkably at desertified cropland due to soil coarse sand increase, soil moisture declining, soil temperature increase, and most of clay and soil OM blown out by wind erosion in the processes of desertification.

Table 4. Coefficient of correlation in the biomass with environment factors

Items	corre.coef.	Items	corre.coef.	Items	corre.coef.
water content	0.9202*	Soil temp.	-0.9475*	Organic matte	0.7972
Available N	0.9423*	Available P	0.6956	Available k	0.7854
Total N	0.7972	Total P	0.7622	Total K	0.9096*

*p£¼0.05, **p£¼0.01

Discuss and Conclusion

Most part of semi-arid and agro-pasturage region in North China is undergoing desertification. Rainfed system, as the larger part of cropland in this region is uncovered at most part of a year (from the middle of Sep. to early of May) because of a short growth period in this region. Therefore, the cropland is easy to erode under a strong and frequent wind condition. In the processes of cropland desertification, the clay and soil OM had been blown away and the coarse content of soil increased in the topsoil. In this study, by comparison with ND, the soil OM and clay were decreased by 84.3%, 66.2%, but the soil particle size at 0.05-1mm increased 2.33-fold in SD. The soil environment of soil moisture, soil temperature and nutrient had deteriorated significantly because of soil OM and clay loss by erosion. At first, the soil water capacity and soil moisture reduced. The average of soil moisture in ND was 15.1% during growth period, but 3.1% in SD. During a dry time, the former was 9.2% and the later was 2.3%. Soil temperature was increased and fertility decreased because of a low water capacity and a high coarse content in soil. By comparison with ND, the average of soil temperature in SD was higher 0.9°C during growth period, the maximum margin at 2.8°C. The OM, total N, total P, total K, available N, available P, and available K in SD were decreased by 66.2%, 72.8%, 59.4%, 9.3%, 69.0%, 27.5%, and 56.3%, compared to that in ND, respectively.

The spring is more windy and frequent in semi-arid and desertification region of North China on the desertified cropland. The local farmers usually sow crop such as millet, sorghum and green bean, which are drought-enduring crops with short growth period. These croplands were originally used as grassland for grazing. After conversion of grassland to farmland, for first several years the farmer used to plant these crops

The biomass of green bean in LD was decreased by 15.3% compared with that in ND, 31.9% in MD and 60.5% in SD, respectively. Though the causes for the incline of crop yield are complex much, the deficient of water and the lack of nitrogen have taken a vital role in the formation of crop biomass in this region.

The available nitrogen and soil moisture in SD, which was 13.0mgkg^{-2} and 2.3 % accounted for 31% and 25% that in ND, have not met apparently the demand of crop survival. In a dry year, or temporal drought, the crop yield in SD decreased significantly and was sometimes nothing to harvest. The results of correlation analysis on crop yield and available N and soil moisture had shown this exchange too. With the formation processes of green bean biomass, the soil environment deterioration resulted in rapid curtail of growth period, photosynthetic efficient and daily rate of biomass accumulation declining. This conclusion is the same as that of related researchers in effect of soil environment deterioration on maize yield. The decline of crop yield has a negative correlation with soil temperature, and the correlation coefficient is -0.9907. Apparently, rising soil temperature is a vital reason for declining of agricultural production because of cropland desertification.

In the semi-arid and desertification region of North China, desertified area has spread at a rate of 2000 km^2 per year recently, in which 23% resulted from cropland desertification. There are two reasons leading to cropland desertification. One is not immediately to set up windbreak for cropland protection from soil erosion. The cropland, therefore, is easy to be deteriorated by desertification. As a result, the land productivity was reduced absolutely.

The other is that the fallow management system adopted by local farmer does not fit in with the climate and soil condition in this region. This management depends on the natural potential capacity of land for agricultural production []. The cropland was abandoned because of severe desertification

occurring or land productivity declining. The dry and bare surface of abandoned cropland is easy to be desertified in coming spring.

Therefore, strengthening the protection and management of rainfed land not only has significance for agricultural production, but also a vital role for desertification control in this region. Based on our research achievements of many years, we think it is a set of good comprehensive measures for agriculture production and soil erosion control in this region to strengthen construction of shelterbelt, to develop irrigation cropland and to increase use of organic manure in no-irrigated cropland. Therefore, we should extent intercrop and rotation systems of grass and food crop in rainfed cropland.

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